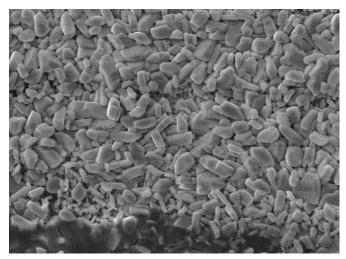


# Advanced Lead Based Active Materials for Critical Battery Applications

Tim Ellis RSR Technologies Dallas, TX

## **Structure Defines Properties: Better Structure = Better Batteries**



Typically lead sulfate grows over the life of a lead acid battery limiting performance, i.e. dense faceted orthorhombic crystals



SUPERSOFT-HYCYCLE<sup>TM</sup> stimulates the formation of platelets composed as bundles of  $PbSO_4$  nanorods. Performance is increased by >2X



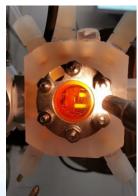




- Argonne National Laboratory
  - Joint Center for Energy Storage Research (JCESR)
  - Argonne Collaborative Center for Energy Storage Science. (ACCESS)
- Real Time analysis of Pb-Acid batteries, an extension of techniques developed for Li ion and other systems
- The APS is one of the worlds premier facilities, the brightest tunable beam with multiple techniques in hand
- CRADA's
  - East Penn Mfg. and RSR Technologies est. Jan 2017 in qualification
  - O US members of the ALABC, results 4<sup>th</sup> qtr. 2018









## Results to Market

- Incorporated in SUPERSOFT-HYCYCLE™ product in product qualification testing
- Presented at "Battery Day" at ANL June 14th, 2017
- Invited to the "BASIC RESEARCH NEEDS WORKSHOP ON NEXT GENERATION FLECTRICAL ENERGY STORAGE" sponsored by the USDoE's Office of Basic Energy Sciences **Battery Workshop**

## INVESTIGATING SULFATION IN LEAD ACID **BATTERIES**

RSR Technologies, East Penn Manufacturing, Argonne National Laboratory

**APPROACH** 

Tim Fister, Matthew Weimer, Eric Coleman, Pietro Papa-Lopes, Nenad Markovic (ANL) Matthew Raiford, Tim Ellis (RSR Technologies) Subhas Chalasani, Kevin Smith (East Penn)

#### MOTIVATION

affecting DCA are:

- Intraplate conductivity - Gassing of O2 and H2

- . Despite 100+ years of use, the energy density of lead acid
- Acceptance (DCA) plays a key role in the energy density and lifetime of batteries, especially during operation at partial state of charge. The major issues
- Dissolution of PbSO, · Models and strategies for
  - the DCA have been inferred from electrochemical testing and post-mortem characterization Argonne has unique canability to

species and morphology

of electrode/electrolyte

species in working cell.

# measure changes in

methods.

. Phase II: Adapt these probes to model NAM

. Initial goal: focus on dissolution of PbSO, at the negative Ph electrode Improve

kinetics of PbSO4 with its morphology.

metal electrodes. Develop operando

diffraction, imaging, and spectroscopy

reversibility by connecting growth/dissolution

. Phase I: simplify reaction by starting with lead

#### **METHODS**

- Synchrotron-based diffraction and tomography
- In situ (high energy, up to 100 keV)
- Real-time (Intensity = 1010 1013 photons/s) - Spatial resolution (10-1000 nm)



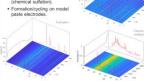
- In situ ICP/MS (part-per-trillion sensitivity) In situ AFM, QCM (atomic scale
- growth/dissolution)
- · World class battery fabrication/testing labs.

#### EXAMPLE: REAL-TIME X-RAY DIFFRACTION

· Single-shot powder diffraction (~0.5 s resolution) · Easily measure the kinetics of sulfation desulfation



naste electrodes



#### **EXAMPLE: HIGH RESOLUTION TOMOGRAPHY**

. Synchrotron-based diffraction and tomography can be used to follow 3D changes in morphology with µm resolution. . CT scans are fast (< 1 min) and use high energy x-rays











## **EXAMPLE: SURFACE SENSITIVE TECHNIQUES**

· Surface diffraction and in situ atomic force microscopy provide atomic scale information on the nucleation and growth of PbSO4 single crystal surfaces.





- . The growth and dissolution of PbSO<sub>4</sub> in lead acid batteries is a multidimensional problem ranging from atomic scale changes at the charged interface to transport
- · Argonne has developed tools capable of measuring sulfation during operation of a lead acid cell to validate and extend existing models based largely on

### **NEXT STEPS**

- . Develop paste electrodes further.
- . Begin analogous studies on the positive electrode material. · Incorporate modeling of crystal growth and continuum pack-level features.





CONCLUSIONS

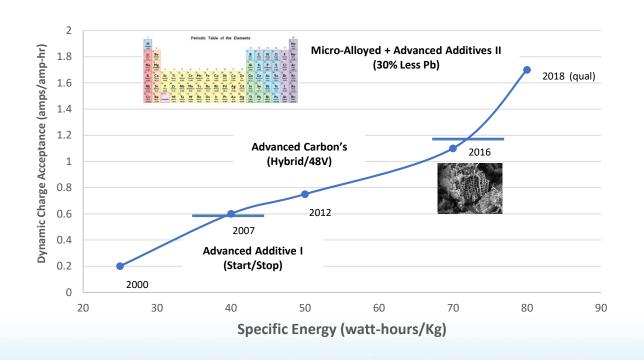








## **Progress in Performance**





# **CPHRI Lead Battery Pilot Programs**

- Advanced Battery Concepts: Workplace and Environmental Manufacturing Emissions Reduction through Green-Seal® Manufacturing Techniques
- Hammond Group Inc.: Improved Charge Acceptance for Group 31 Bus Batteries and Improved Charge Efficiency on Deep Cycle Batteries
- Doe Run: Flubor Hydrometallurgical Process for the Recycling of Pb-Acid Battery Scrap



# **Lead Based Energy Storage**

- Improvements from research programs increase performance allowing significant reduction in lead content and longer cycle life, = Less Lead/Kw-hr
- Cost-effective displacement of fossil fuel based energy sources in transportation, grid storage and behind the meter applications, = Lower energy cost/Kw-hr and Lower emissions/Kw-hr
- Opportunities for further emission reductions associated with lead battery manufacturing and/or recycling, continue to lower the externalities of Lead usage
- True market-ready drop-in replacement with no compatibility issues, safety issues or need for more complex systems (i.e., to manage multiple chemistries).





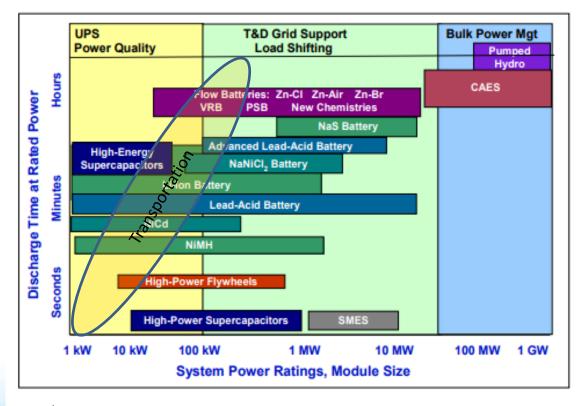
# Thank You

## **USDoE** forward looking metrics

- Cost <\$80/kw-hr (acquisition) = cost of hydrocarbon fuel</li>
- Per Cycle cost <<\$0.10/kw-hr per cycle (operational cost)</li>
- Recharge from 20% -> 80% <20 minutes</li>
- Puts rechargeable energy = fossil fuels



# One Chemistry for Societies Applications



DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA



# **Cost of Ownership Comparison**

	STOP-	MICRO	MILD	FULL	PLUG-IN	ELECTRIC
	START	HYBRID	HYBRID	HYBRID	HYBRID	VEHICLE
Idle Elimination	✓	✓	✓	✓	✓	✓
Regenerative Braking		✓	✓	✓	✓	✓
Acceleration Boost			✓	✓	✓	✓
Electric-only drive				✓	✓	✓
Electric motor power			10-20 kWh	30-40 kWh	50 kWh	above 80 kWh
Electric motor power  Preferred primary battery	lead acid	lead acid	10-20 kWh Li+	30-40 kWh Li+	50 kWh Li +	above 80 kWh Li+
·	lead acid 20	lead acid 45				
Preferred primary battery			Li+	Li+	Li+	Li+
Preferred primary battery  Annual gasoline savings	20	45	Li+ 260	Li+ 300	Li + 450	Li+ 600

<sup>\*</sup>Based on 15,000 miles a year, \$3.00 per gallon of gasoline. Study was of consumer level cars under approximately \$35,000 MSRP.



## **Advanced Lead Acid Battery Consortium (ALABC)**

- International consortium of 77 companies
- Leading development of technology for Pb-Acid
- Leading activities drivetrain development
  - Stop/Start: Gas, Diesel, NGV
  - 12V/48V/200V Mild/Micro hybrid systems
  - Electric supercharging & turboelectric energy recovery
- Partners
  - Ford, Hyundai, USDoE, Valeo, AVL Schrick, AGL Resource, Southern California Gas, Ricardo, UK Technology Strategy Board

## The LC SuperHybrid Project

Utilizes advanced lead-carbon batteries along with a belt-driven Integrated Starter Generator and an electric supercharger to increase battery charge and engine efficiency, lower carbon emissions and boost performance in 12V and 48V mild/micro hybrid vehicles.





## The Natural Gas Hybrid Vehicle

Combines advanced lead-carbon batteries with a natural gas-powered engine and a factory-built start-stop system in a RAM truck to achieve lower emissions and reduced fuel costs, giving fleet owners a low-cost alternative to conventional trucks.

## The ADEPT Project

Applies 48V "intelligent electrification" concepts using advanced lead batteries to deliver full hybrid equivalent fuel economy and performance with lower CO2 emissions at a significantly lower cost.





## The Kia Optima T-Hybrid

Offers a 48V micro/mild-hybrid propulsion system featuring advanced lead-carbon batteries similar to the LC SuperHybrid concept and is the first of its kind to be demonstrated in collaboration with a major automaker.

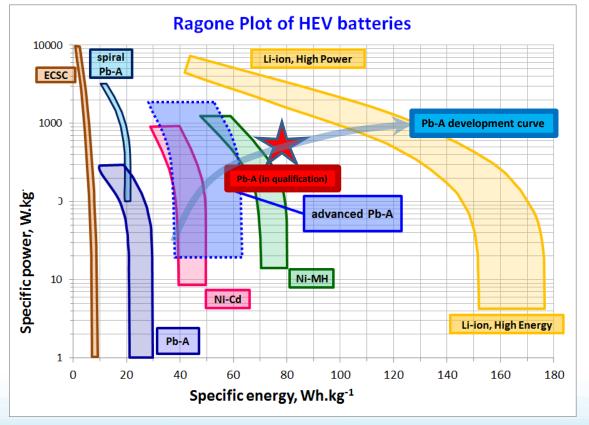
## **The UltraBattery Civic**

Demonstrated that lead-carbon UltraBatteries can out-perform Nickel Metal Hydride batteries in mild hybrids (with start-stop) by running for 160,000 miles in real-world courier duty at varying temperatures with no significant power loss.





# Improvement in Pb Utilization in batteries





## What do we see?

